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The Nature and Effects of Technological Change over the Industry Life Cycle

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Abstract

This paper estimates the nature and effects of quality and cost innovations in the early automobile, personal computer, rigid disk drive, computer monitor, and computer printer industries using industry-level data on firm numbers, price, quantity, and quality along with an equilibrium model of industry evolution. The results challenge the notion that new industries experience a pattern of quality innovation early on followed by cost innovation later on. In the four microelectronics industries the rate of quality improvement does not diminish as the industries evolve. The results for the automobile industry demonstrate that even when the rate of quality improvement is highest early on, the profitability of quality advantages may be higher later on.

JEL codes: **L10**: Market Structure, Firm Strategy, and Market Performance, **L63**: Industry Studies: Microelectronics, **O31**: Innovation and Invention.

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1. Introduction

Gort and Klepper (1982), Klepper and Graddy (1990), and Agarwal and Gort (1995) show that as a new industry evolves from birth to maturity price falls, quantity rises, and the number of firms initially rises and then falls. These authors and theorists such as Hopenhayn (1994), Jovanovic and MacDonald (1994) and Klepper (1996) attribute the observed trends in price, quantity and the number of firms to technological innovations that occur at the industry level in new industries.

While the issue of the primary cause of the observed trends - innovation - appears to be settled, we still lack knowledge about the relative importance of different types of innovation as an industry evolves. A commonly expressed view is that the rate of quality improvement is highest when the number of firms is rising. Over time, the rate of quality improvement diminishes and the rate of cost improvement rises, and this change causes the decline in the number of firms (the shakeout). Utterback and Abernathy (1975) find this pattern in the automobile industry and Klepper (1996) describes several studies that find this pattern in other industries.

The pattern of quality innovation early on followed by cost innovation later on has been sufficiently documented that it may be called a stylized fact. However, whether we observe this pattern in recent high-tech industries is an open question. Further, because quantifying quality and cost innovation typically relies on either anecdotes, counting patents, or using some other sampling method, the links between innovation and profitability have not been studied closely. For example, one might be tempted to infer from earlier work that since the rate of quality innovation is highest early on, the profitability of quality innovation diminishes as the industry evolves.

The goal of this paper is sort out how quality, cost, and the profitability of innovating evolve over an industry's life cycle. To accomplish this I adopt a novel approach to the problem of measuring the nature and effects of innovation: I estimate innovations using industry-level data on firm numbers, price, quantity, and quality along with a simple, tractable, dynamic industry equilibrium model. The model provides a link between industry-level observables, underlying innovations, and profit.

The model employs flexible quality and cost ladders. Firms take their industry's quality and cost ladders as given and make entry, exit, quantity, and investment decisions optimally. Given the ladders the model generates predicted patterns in firm numbers, price, quantity, and quality. These patterns are fit to the data to estimate the quality and cost ladders. Then I analyze the estimated trends in costs, profit, and investment that the model generates.

The model extends previous dynamic equilibrium models of industry life cycles (Hopenhayn (1994), Jovanovic and MacDonald (1994) and Klepper (1996)) in two ways. First, it allows for both quality improvements and changes in variable and fixed costs. The results show that all three types of innovation play important roles as industries evolve. Second, it is flexible: the model allows the opportunities for innovation in different industries to evolve according to what the trends in the industry-level observables suggest.

The five products I study are automobiles (1895-1929), personal computers (1975-1999), rigid disk drives (1980-1999), computer monitors (1971-1999), and computer printers (1970-1999). Figures 1-5 graph firm numbers, price, market quantity, and quality in each industry. All five industries have evolved the way Gort and Klepper (1982) describe, although monitors and printers have not yet reached the shakeout stage. The analysis compares the early automobile industry to the four recent microelectronics industries. The model can be estimated using any industry as long as data on firm numbers, price, quantity, and a measure of quality are available. Of these data, typically the measure of quality is the most difficult to obtain, and the difficulty of obtaining such a measure for other products limits the scope of this study. The data is discussed in the following subsection.

Figures 1-5 here

The estimation results show that typically quality improves, the variable-cost function shifts down and fixed costs rise as an industry evolves. However, the estimated rates of change in quality and the cost function vary by stage of the life cycle and by industry. The automobile industry evolves as Utterback and Abernathy (1975) and Klepper (1996) describe: the estimated rate of quality change is highest early on when firm numbers are rising and the estimated rate of cost-function change is highest later on. The other industries depart from this pattern in several ways but the most distinctive difference is that the rate of quality change tends to rise as the industries evolve rather than fall. This suggests that the opportunities for innovation in modern high-tech industries may evolve in systematically different ways from previous ones.

The results highlight the importance of linking innovation to profitability. The results show that determining the rate of innovation during a period is not sufficient for determining the profitability of innovating during the period: the rates of change in quality and cost interact with the levels of quality and cost to determine profitability. For example, in the automobile industry, even though the estimated rate of quality change is highest early on, the estimated profitability of improving quality is highest late in the life cycle, when firms are larger and more capable of exploiting a given quality advantage.

1.1. Data Sources and Method

Spence (1984) has argued that quality improvements are formally indistinguishable from cost improvements, and if the unit of analysis is services provided rather than quantity purchased his argument is correct. However, the data used here measure quantity, price per unit of output, and services provided by each unit of output (quality) separately. This makes it possible to distinguish between quality improvements that shift the demand curve and cost reductions that lower price and cause movements along the demand curve. Firm numbers are also used in the estimation routine. In every case, the data describe *manufacturers* and exclude related component producers, software firms, and service providers.

All of the data is industry-level data that describes the American market. The reliance on industry-level data has some weaknesses. For example, changes in the skewness of the firm size distribution are not used to estimate the parameters. This affects the results below - the results do not track specific firms, only industry-level trends. Even industry-level data is somewhat difficult to obtain, and not all of the data is available every year.

The automobile quality series is derived from the quality changes computed by Raff and Trajtenberg (1997). The disk drive quality series is estimated using the average areal density of all models produced each year, based on data from the *Disk/Trend Report, Rigid Disk Drives*. The areal density measures how much information can be stored on a square inch of disk and has long been considered to be the standard measure of disk drive quality.

For personal computers, monitors, and printers, the following identity is used to construct a series for average quality:

$$\frac{P_{t+1}}{P_t} \equiv \frac{P_{s(t+1)}}{P_{st}} \frac{\gamma_{t+1}}{\gamma_t}, \tag{1.1}$$

where P_t and P_{t+1} represent actual industry prices, $\frac{P_{s(t+1)}}{P_{st}}$ represents what the industry price ratio would be if quality did not change between period t and period $t+1$, and γ_{t+1} and γ_t represent average qualities. The price ratio is expressed as a constant-quality price ratio multiplied by a quality ratio. The official indexes used by the Bureau of Economic Analysis were used to construct constant-quality price ratios. Quality ratios were constructed by dividing the actual price ratios by the constant-quality price ratios.

It would be possible to use the quality series to estimate the rates of quality change directly. However, the goal of this paper is to estimate cost changes as well as quality changes and to link both to changes in firm numbers, price, quantity, investment, and profit over the life cycle. The rate of cost improvement could be roughly approximated using the rate of price reduction but as shown below distinguishing between variable and fixed costs requires additional information. Further, linking the estimated quality and cost improvements to investment and profit requires the structural model developed in the next section.

Firm numbers, price, and quantity in the automobile industry are from Thomas (1977). The analysis of the automobile industry stops in 1929 for two reasons. First, the industry entered maturity in the late 1920's. Second, the Great Depression began in the 1930's and caused dramatic changes in price, quantity, and firm numbers. Isolating the impact of the depression on the automobile industry is beyond the scope of this study.

Firm numbers in the rigid disk drive industry are from the *Disk/Trend Report, Rigid Disk Drives*. Firm numbers in the personal computer industry are from Stavins (1995) and the *Thomas Register of American Manufacturers.* The data includes desktop and portable computers. Firm numbers in the other three industries are from the *Thomas Register of American Manufacturers.* Price and quantity information for personal computers, disk drives, monitors, and printers is from the *Information Technology Industry Data Book.* The price is average suggested retail list price, unadjusted for inflation. All of the price series are deflated using the CPI.

In the model all entrants are producers that are capable of shipping in quantity. However, as Carroll and Hannan (2000) have noted, some of the firms listed in industry directories may be *preproducers* - new firms that cannot yet ship in quantity. All of the sources used here attempt to exclude or identify firms that are not capable of shipping in quantity and only those firms deemed capable are included in the analysis below.[1]

In addition to the above data, some information on the numbers of the various types of high-tech firms in each market was obtained using a variety of sources including the *Disk/Trend Report, Rigid Disk Drives,* Dorfman (1987), *The Market Share Reporter, Standard and Poor's Industry Surveys,* and Thomas (1977).

Because the data is annual, the estimated quality improvements are made up of all the quality improvements that occur over each year, and the estimated cost improvements are defined similarly.

2. The Model

The model describes the evolution of a single industry in a framework with discrete time, an infinite horizon, and a continuum of firms. The industry has a quality ladder and a cost ladder, and the shapes of each determine the magnitude of the available innovations each period. The shapes of each ladder are known and fixed. This implies that firms cannot influence the direction of technological change. Instead, each period each firm invests in an attempt to be a leader on each ladder, and the probability of success is a random function of investment.[2] The quality and cost ladders and the probability-of-success functions are

[1] Carroll and Hannan describe preproducers in the early automobile industry and establish that there were always large numbers of such firms. In the model here preproducers would be potential entrants.

[2] Note that these assumptions rule out an environment in which firms might choose among several possible paths of innovation and influence the magnitude of the resulting improvements. The assumptions fit best in cases like the following: Suppose that Intel develops a new chip. From a personal computer manufacturer's point of view, the improvement in processing power is exogenous (it is determined by the chip). Taking the magnitude of the improvement as given, PC manufacturers invest in an attempt to be among the first to incorporate Intel's new chip into their machines.

Clearly not all innovation is of this type, and it would be interesting to extend the model to endogenize the path of innovation. However, given that this study relies on industry-level aggregated data, empirically collectively referred to as the industry's "technological opportunities."

Disentangling quality and cost changes is challenging because in reality the two types of changes often occur together. Using separate ladders for quality and cost distinguishes the profitability of quality and cost innovations, but decomposing innovation this way has empirical implications: if improving quality typically requires accepting higher costs and reducing costs requires sacrificing quality then the estimation results reported below overstate the profitability of improvements of each type because the model ignores these adverse effects. If on the other hand improving quality is associated with lower costs, as when using fewer components improves product reliability *and* costs, then the effects on profit and investment are in the other direction. Quantifying the magnitude of these types of effects is not possible using the available data.

Two additional assumptions simplify computations. First, all of the followers catch up to the leaders on each ladder at the end of each period. This assumption implies that the diffusion of quality and cost changes takes one period. Second, obtaining a leadership position on a ladder in one period does not give the firm an advantage in innovating in future periods: all firms have access to the same probability-of-success function regardless of their current technology. As described in detail below, this implies that in equilibrium all firms invest the same amount in each type of innovation each period and that some followers can leapfrog the current leaders to become leaders the following period. The two assumptions together imply that there is no gain to being an imitator who always follows, as in Nelson (1988) and Eeckhout and Jovanovic (1998).

The evolution of the industry proceeds as follows. Initially, all firms are on the first rung on each ladder, so all have the same product qualities and cost functions. In the first period, firms can invest in an attempt to move up to the second rung on each ladder. Those that are successful move to the second rung in the second period, while those that fail and new entrants remain on the first rung. In the second period, and in each subsequent period, there are two relevant rungs on each ladder - a rung for leaders (firms that innovated in the previous period) and a rung for followers (firms that did not innovate in the previous

it is not possible to sort firms onto different paths. Therefore, exploring multiple paths of innovation would require additional data as well as an extended model.

period). In the second period, firms can invest in an attempt to move up to the third rung on each ladder. Those that are successful are on the third rung in the third period, while those that fail and new entrants are on the second rung. Both the leader and the follower rungs increase by one each period (after the first), so the followers catch up to the former leaders, but the new leaders continue to be one rung ahead. In period t, leaders are on rung t and followers are on rung $t-1$.

Firm numbers, price, and quantity depend on the industry's technological opportunities. The levels of quality and cost interact with the rates of change in each to determine the profits of firms with advantages. Other things equal, periods of large improvements in quality or cost create high profits that lead to increased investment. Periods of low improvements lead to less investment. The model also allows firms to experience exogenous quality reductions or cost increases. Of course, in equilibrium firms do not invest in such quality and cost changes. In this case, all firms are followers, but it is assumed that followers continue to move up a rung each period so the industry continues to evolve.

2.1. The Firm's Problem and Market Supply

Each period t each firm decides whether to be in the industry or not. A firm in the industry in period t chooses a quality-cost combination, an output, and how much to invest in quality and cost improvements. For now, take the firm's quality-cost combination as given and suppress the firm type and t notation.

A firm chooses its output by maximizing profits taking the price it faces as given. Let profits $\pi(\gamma, a, f)$ be defined as

$$\pi(\gamma, a, f) = \max_{q} p(\gamma)q - c(a, q) - f, \tag{2.1}$$

where γ is the firm's product quality (a level of services per unit of output), a is the firm's variable cost parameter, f is the firm's fixed cost, $p(\gamma)$ is the price the firm faces, and q is output. Assume that $c(a, q)$ is strictly increasing and strictly convex in q, that $c(a, 0) = 0$, and that when a decreases, the marginal-cost curve shifts down. The assumptions on the cost function ensure that the number of firms in the market is always positive by ensuring that a firm's size each period is limited by its process technology. The interpretation of fixed costs is standard - they include plant and equipment rental costs and other opportunity costs. Firms in the model differ only by their γ, a, and f parameters.

A firm chooses its investments in quality and cost improvements by maximizing its value. Advancing on the quality ladder changes quality (γ), and advancing on the cost ladder changes the variable and fixed cost combination (a and f).[3] Since the shape of each ladder is determined exogenously, a firm's investments do not affect the magnitude of the improvement it obtains. Instead, each firm's investments affect its probability of becoming a leader the following period. Denote a firm's investments in quality and cost improvements by x_q and x_c, respectively, and probabilities of success by $\lambda_q(x_q)$ and $\lambda_c(x_c)$. Assume that $\lambda_i(0) = 0$, $\lambda_i(x_i)$ is strictly increasing, concave, differentiable, and that $\lambda_i'(0) = \infty$ for $i = q, c$. These properties imply that investment is necessary in order to innovate, the probability of success is increasing in investment, there are diminishing marginal returns to investment, and the marginal return to investment is infinite when investment is 0. The last assumption ensures an interior solution, as long as innovating is profitable. The functions $\lambda_q(.)$ and $\lambda_c(.)$ are the same for all firms, and are referred to as the investment technology below.

Firms that successfully innovate obtain either a quality advantage, a cost advantage, or both, that lasts for one period. After that, the improvement is available to every firm. Therefore, in every period after the first there are five types of firms: firms that have both a quality and cost advantage, firms that only have one or the other, existing firms that have no advantage, and new entrants, who by assumption have no advantage. Below, firms in the first three groups are called high-tech firms, and firms in the last two groups are called low-tech firms. In order to remain a high-tech firm, a firm has to successfully innovate each period. Low-tech firms can become high-tech firms in the following period if they are successful at innovating.

Below, variables that refer to firms with both quality and cost advantages, just quality advantages, just cost advantages, and no advantage, have qc, q, c, and 0 superscripts, re-

[3] Note that investment in cost reduction can be profitable even if one component of cost rises as long as the other component falls enough. The estimates reported below suggest that variable and fixed cost tradeoffs occur.

spectively. For example, denote the number of each type of firm in the market at time t by n_t^{qc}, n_t^q, n_t^c, and $n_t^{\mathbf{0}}$. Note that if each firm uses the newest technology available to it, then $f_{t-1}^{qc} = f_{t-1}^c = f_t^q = f_t^{\mathbf{0}}$, $a_{t-1}^{qc} = a_{t-1}^c = a_t^q = a_t^{\mathbf{0}}$, and $\gamma_{t-1}^{qc} = \gamma_{t-1}^q = \gamma_t^c = \gamma_t^{\mathbf{0}}$.

Now consider the choice of a quality-cost combination. A low-tech firm has no choice and must use $(\gamma_t^{\mathbf{0}}, a_t^{\mathbf{0}}, f_t^{\mathbf{0}})$, but a firm on a higher rung can decide to use the low-tech technology instead. This assumption ensures that being on a higher rung cannot make a firm worse off. For example, high-quality firms, facing a higher price, have a greater incentive to produce a larger quantity, and therefore might resist adopting processes with high variable costs, even if low fixed costs are obtained. Ex ante, firms do not know whether they will obtain a quality advantage or not, so they still invest in both types of improvements.

Given a quality-cost combination and assuming that the firm's output is chosen optimally, the value function of a low-tech firm is given by

$$\begin{aligned} V_t^{\mathbf{0}} = \quad & \max\{\max_{x_q,x_c}[\pi_t^{\mathbf{0}} - x_q - x_c + \delta(\lambda_q(x_q)\lambda_c(x_c)V_{t+1}^{qc} + \lambda_q(x_q)(1-\lambda_c(x_c))V_{t+1}^q \\ & +(1-\lambda_q(x_q))\lambda_c(x_c)V_{t+1}^c + (1-\lambda_q(x_q))(1-\lambda_c(x_c))V_{t+1}^{\mathbf{0}}) - \delta V_{t+1}^{\mathbf{0}}], 0\}, \end{aligned} \tag{2.2}$$

where δ is a discount factor. The value of operating outside the industry is normalized to 0. Therefore, a firm exits if the value of operating in the industry is negative.

The value functions of the high-tech firms differ from $V_t^{\mathbf{0}}$ by current profits, but are otherwise identical. Since all firms have the same future opportunities and investment technologies, all firms invest the same amounts in each type of innovation.

In every period, market supply in terms of quantities is given by

$$n_t^{\mathbf{0}}q_t^{\mathbf{0}} + n_t^c q_t^c + n_t^{qc} q_t^{qc} + n_t^q q_t^q. \tag{2.3}$$

where $q_t^{\mathbf{0}}$, q_t^c, q_t^{qc}, and q_t^q represent quantities. Market supply in terms of services is given by

$$\gamma_t^{\mathbf{0}} n_t^{\mathbf{0}} q_t^{\mathbf{0}} + \gamma_t^c n_t^c q_t^c + \gamma_t^{qc} n_t^{qc} q_t^{qc} + \gamma_t^q n_t^q q_t^q, \tag{2.4}$$

where each type of firm's quantity is weighted by its quality level.

2.2. The Consumer's Problem and Market Demand

Assume that consumers value services provided by goods, where the level of services provided by a quantity is given by $s = \gamma q$ (each unit of output is weighted by its quality). Given this assumption, goods are perfect substitutes in providing services, so demand is a function of price per unit of quality. If consumers are willing to buy all quality types in every period, then it must be true that

$$\frac{p_t^0}{\gamma_t^0} = \frac{p_t^c}{\gamma_t^c} = \frac{p_t^q}{\gamma_t^q} = \frac{p_t^{qc}}{\gamma_t^{qc}}. \tag{2.5}$$

Denote the market demand for services by $D(\frac{\gamma_t}{p_t})$, where $D(.)$ is an increasing function of $\frac{\gamma_t}{p_t}$, the common quality-price ratio.[4]

2.3. Equilibrium

In equilibrium firms enter or exit and choose their quality-cost combinations, quantities and investments optimally, and consumers choose their quantities optimally. The following market-clearing condition, which equates the demand for services with the supply, must be satisfied:

$$D(\frac{\gamma_t}{p_t}) = \gamma_t^0 n_t^0 q_t^0 + \gamma_t^c n_t^c q_t^c + \gamma_t^{qc} n_t^{qc} q_t^{qc} + \gamma_t^q n_t^q q_t^q. \tag{2.6}$$

Optimal entry and exit of low-tech firms implies that $V_t^0 = 0$ for all t. The outside option ensures that V_t^0 cannot be negative, and free entry implies that a low-tech firm's payoff in the industry cannot be positive in equilibrium. If low-tech firms are in the market every period, then the value of operating a low-tech firm in the industry is 0 every period. The remainder of the paper focuses on this case.

[4] Consumers can be heterogeneous. Suppose consumers solve $\max_{q^0,q^q} U = M - p^0 q^0 - p^q q^q - \theta e^{-(\gamma^0 q^0 + \gamma^q q^q)}$, where M is income and θ is a heterogeneous taste parameter. Given prices and qualities, there is a value of θ such that consumers with a lower value of θ purchase nothing. Thus, new market segments can emerge as price drops and quality improves.

2.4. Identifying Innovation Using Industry Level Data

In order to estimate patterns in quality and cost innovations the model must be capable of identifying the types of innovation that occur using industry-level data. Independent quality measures are used to help estimate the quality ladders so the main problem is distinguishing between variable and fixed cost changes. To establish that the model can do this and to clarify the impacts of the different types of innovation on industry observables, a series of analytical results is presented in Table 1, with formal proofs provided in Appendix A. The proofs employ several simplifying assumptions that isolate the effects of each type of innovation on observables.

Table 1 here

The effects in Table 1 occur after an improvement has diffused to all of the firms in the industry. For example, firms with a quality improvement initially face a higher price than firms without it because they have a higher-quality product, but after one period the quality improvement spreads to all existing firms and potential entrants. Firm entry causes price to fall. The result is that the price most firms face is determined by the cost parameters; only firms that have obtained the next quality improvement face a higher price.

Table 1 provides insight into how the model identifies patterns in quality and cost innovations in the data. For example, a fall in price must be due to cost innovations, while an increase in market quantity can be due to either quality or cost innovations. Therefore, if market quantity rises while price remains roughly constant, then quality improvements are likely to be important (although changes in the variable and fixed cost mix can matter as well).

To see how the model distinguishes changes in variable and fixed costs, note that the effects of the two types of innovation on quantity per firm differ. Variable-cost reductions shift the marginal cost curve downward; quantity per firm rises. Fixed-cost reductions cause price to fall (in order to satsify the equilibrium condition $V_t^{\mathbf{0}} = 0$); quantity per firm falls. Thus, if quantity per firm in the data rises, the model suggests that either variable costs are falling or fixed costs are rising. The interaction of the quantity-per-firm effects and the price effects determine the magnitude of the predicted changes in variable and fixed costs. For example, if quantity per firm in the data rises while price falls dramatically, then the model suggests that both variable and fixed costs are falling, but if price stays roughly constant then the model sugggests variable costs are falling and fixed costs are rising.

3. Estimation

The estimation method is similar to that used by Jovanovic and MacDonald (1994) and is described in detail in Appendix B. Given some functional forms, the model is simulated. Time series for firm numbers, price, quantity, and average quality are outcomes of the equilibrium of the model. By choosing parameters of the model appropriately, it is possible to make the observables that the model generates follow the main patterns in the observables in a given industry. The estimation algorithm essentially performs a curve-fitting exercise.

The estimation results overstate the contribution of quality and variable and fixed cost changes to an industry's evolution because other factors are not in the model (brand names and network effects are two examples). However, the estimation results still yield some broad trends in quality, variable and fixed costs, profits and investments that should be observed if the forces of the model are partly responsible for the observed dynamics. The method asks, *what does the model say the patterns in innovation and profits are in an industry that evolves as the one being studied has?*

3.1. Functional Forms

The cost and investment technology functions in each industry have the following forms:

$$c(a,q) = a\frac{q^2}{2}. \tag{3.1}$$

$$\lambda_c(x_c) = \frac{\alpha_c x_c^{1/2}}{1+\alpha_c x_c^{1/2}}. \tag{3.2}$$

The $\lambda_q(x_q)$ function has the same form as $\lambda_c(x_c)$,with parameter α_q.

The demand function for services has the form

$$D_t = \exp\{d_0 + d_1 \ln\left(\frac{\gamma_t^0}{p_t^0}\right) + d_2\left(\ln\left(\frac{\gamma_t^0}{p_t^0}\right)\right)^2 + d_3\left(\ln\left(\frac{\gamma_t^0}{p_t^0}\right)\right)^3\}. \tag{3.3}$$

The cost and quality ladders are specified using flexible functional forms that differ by industry. The processes keep track of the quality and cost parameters available to low-tech firms each period after the first ($\gamma_t^0, a_t^0,\ f_t^0$). Recall that leaders each period are one rung ahead on these ladders. The amount of flexibility required for each ladder is determined by the goal of describing the main trends in firm numbers, price, quantity, and quality. Likelihood ratio tests were used to determine the degree of flexibility required in each industry.[5]

As an example, in the automobile industry the following functional forms are used:

$$\gamma_t^0 = \exp(b_0 + b_1 t + b_2 t^2 + b_3 t^3) \tag{3.4}$$

$$a_t^0 = \frac{\exp(w_1 + w_2 t + w_3 t^2 + w_4 t^3)}{\exp(w_5 + w_6 t)} \tag{3.5}$$

$$f_t^0 = \exp(w_1 + w_2 t + w_3 t^2 + w_4 t^3) * (\exp(w_5 + w_6 t))/2. \tag{3.6}$$

The first rung of each ladder is determined by the restrictions $a_1^0 = a_2^0$, $f_1^0 = f_2^0$, and $\gamma_1^0 = \gamma_2^0$. The functional forms for the other industries are similar, and for the sake of brevity they are omitted. The discussion below focuses on the estimated changes in a_t^0, f_t^0, and γ_t^0 in the different industries, and not on the values taken by the various w_i and b_i parameters.

4. Empirical Results

Estimation results for the five industries are illustrated in Figures 6-25. There are four figures for each industry. In the first two, all of the series are normalized to lie between 0

[5] The formal testing procedure starts with a simplified version of the model with no investment. Functional forms that appear to be sufficiently flexible to explain the observed patterns in firm numbers, price, quantity, and quality are chosen. Then likelihood ratio tests are used to determine whether adding or removing parameters makes a statistically significant difference in the fit. The simplified version of the model is used to perform the tests because it computes much faster than the complete model.

and 1 so that all series fit on the graph. The first figure shows the firm numbers, price, and market quantity data for the industry along with the estimated patterns in these series. The second figure shows the estimated trends in the average quality γ, the average variable-cost parameter a, and the average fixed cost f. Each period the average quality is computed by weighting each firm by its quantity and quality and then dividing by the market quantity. The average variable-cost parameter and fixed cost are computed by weighting each value by the number of firms with that value and then dividing by the total number of firms. The third figure shows the estimated trends in profits for the four types of firms, and the fourth figure shows the estimated trends in investment in quality and cost improvements. Profits and investment are measured in 1983 dollars.

Figures 6-25 here

This section summarizes the conclusions that can be reached from the estimation results and describes some of the distinct features of each industry's evolution. Of course, because there are only five industries being studied, all general conclusions are somewhat tentative. Each industry is divided up into three stages.[6] Stage 1 is the takeoff stage, an initial period of sustained net entry of firms. Stage 2 is the plateau. It begins when the net entry rate falls below 15% and is a period of either no change or gradual change in firm numbers. Stage 3 is the shakeout stage. It begins when the net exit rate exceeds 15% and is a period of sustained net exit. Not all industries experience all stages in the time period being studied - monitors and printers do not enter stage 3 before 1999.[7]

The estimation results show that the five industries experienced different patterns in innovation over the life cycle. Tables 2, 3, and 4 describe the estimated average rates of change in average quality (γ), the average variable-cost parameter (a), and average fixed costs (f) in each stage in each industry, and Figures 7, 11, 15, 19, and 23 illustrate how the

[6] Stage 1 corresponds to Gort and Klepper's birth and takeoff stages, Stage 2 is the plateau, and Stage 3 is the shakeout. The method used to determine stages here (the 15% entry/exit rate) is simpler than the discriminant analysis used by Gort and Klepper.

[7] The automobile industry enters stage 2 in 1909 and stage 3 in 1923, the personal computer industry enters stage 2 in 1987 and stage 3 in 1993, the rigid disk drive industry enters stage 2 in 1982 and stage 3 in 1992, the monitor industry enters stage 2 in 1986, and the printer industry enters stage 2 in 1985.

series evolve in each industry.

Tables 2-4 here

Estimated quality rises in every stage in every industry, but the rate of change varies considerably by stage and by industry; there is no one pattern. In the automobile industry the rate of quality change is highest in stage 1 and the rates in stages 2 and 3 are very low and roughly equal. In the personal computer industry the rate of quality change is high in stage 1, lower in stage 2, and then high again in stage 3. The rate is highest in stage 3. In the rigid disk drive industry the rate of quality change rises over the life cycle. In the monitor industry the rate is the same in stages 1 and 2, and in the printer industry it rises from stage 1 to stage 2. On average, the rate of quality change is highest in stage 3.

The estimated variable-cost function shifts down in every stage in every industry, but as with quality the rate of change varies by stage and by industry. In the automobile industry, the greatest percentage decreases in the variable-cost function occur in stage 2. This is also the case in the rigid disk drive industry. In the personal computer industry, the greatest percentage decreases occur in stage 3, and in the monitor and printer industries they occur in stage 1. Estimated fixed costs rise in most cases, but fall in the monitor industry and in stage 2 of the printer industry. In the automobile industry, fixed costs rise at the lowest rate in stage 2. This is also the case in the personal computer industry. In the rigid disk drive industry they rise at the lowest rate in stage 1, and in the monitor industry the greatest percentage decreases occur in stage 1. In the printer industry fixed costs rise in stage 1 and fall in stage 2.

The effects of cost innovations on firms' costs depend on the combination of variable and fixed costs. Using the by-stage rates of change in the two components of the cost function, the rate of cost improvement in the automobile industry appears to be greatest in stage 2 and the rate of cost improvement in the monitor industry appears to be greatest in stage 1, but it is difficult to reach firm conclusions in the other industries. In the other industries there is a tendency for changes in the two components of the cost function to offset each other in each stage - Tables 3 and 4 show that stages with larger rates of decrease in the variable-cost function tend to also have larger increases in fixed costs. Figure 11 shows that the personal computer industry is a particularly striking example of this pattern: changes in the two series offset each other over the entire life cycle.

Even though the variable and fixed costs tradeoffs sometimes caused the profitability of cost innovation to be low, the estimates suggest that being a step ahead on the cost ladder was profitable in almost every case: the estimated investment in cost improvements is positive in every period in every industry with the exception of the automobile industry during 1896, 1927, and 1928.[8]

Overall, the results for the automobile industry are consistent with the results obtained by Utterback and Abernathy (1975): the rate of quality improvement is highest during stage 1 when firm numbers are rising and then falls, and the rate of cost improvement is highest later on. The other industries exhibit a variety of patterns that differ from this case: the estimated rates of quality improvement rise from stages 1 to 2 in the disk drive, monitor, and printer industries, and from stages 2 to 3 in the personal computer and disk drive industries; the rate of change in the variable cost function is higher in stage 1 than in stage 2 in both the monitor and printer industries; and in the computer, disk drive, and printer industries variable and fixed cost tradeoffs occur as the industries evolve. Perhaps the most distinctive difference between the microelectronics industries and the automobile industry is that the rate of quality change tends to rise as the industries evolve rather than fall. In the model, this is due entirely to the exogenously available opportunities for quality improvements. The results suggest that the nature of the opportunities for innovation may be different in modern high-tech industries.

Given the different patterns in innovation it is not surprising that there is no consistent pattern of quality innovation being more profitable than cost innovation or vice versa. Table 5 shows that in the automobile industry, quality advantages are more profitable than cost advantages in stages 1 and 3, but cost advantages are more profitable in stage 2. In the

[8] In the automobile, disk drive, and printer industries, visual inspection of the figures suggests that variable costs reach 0 before the end of the series. However, the figures are misleading; substantial rates of variable-cost reduction continue to occur, as reported in Table 3. In the automobile industry the estimates suggest total costs rose briefly at the beginning and the end of the series; the only way the model can account for this is through exogenous cost-increasing shocks that firms could not avoid.

personal computer and the rigid disk drive industries quality advantages are more profitable over almost all of the life cycle (See the relevant graphs as well). In the computer monitor and printer industries cost advantages are more profitable in stage 1, quality advantages are more profitable in stage 2, and the profitability of innovating tends to decline over time.

Table 5 here

One pattern that emerges is that in each of the industries that experience a stage 3 the profitability of innovating is highest in stage 3, and most of the profit opportunities are in quality improvement, not cost reduction. Investment rises in response to the increased profit opportunities. Figures 8, 9, 12, 13, 16, and 17 show the patterns in the automobile, personal computer, and disk drive industries. The explanation for this in the personal computer and the disk drive industries is straightforward: both industries experience substantial rates of quality improvement in stage 3, and when combined with large scale production technologies, these lead to large profits for quality leaders. In the automobile industry, though, the rate of quality change is relatively low in stage 3. Thus, the estimated profit series demonstrate that determining the rates of change in quality and cost during a stage is not sufficient for determining the profitability of innovating during the stage. In the first stage of the automobile industry the estimated rate of quality improvement is relatively high but the estimated profitability of obtaining a quality advantage is relatively low when compared with later stages. The reason for this is that in the early stages variable costs are high and fixed costs are low, so firms are relatively small. In stage 3 the rate of quality change is lower but firms are large and can incorporate any given quality improvement into more units of output.

4.1. Conclusion

The model presented here extends previous work on industry life cycles by considering quality and variable and fixed cost improvements simultaneously in a flexible framework. The empirical results suggest that dynamic competitive industry equilibrium models can generate reasonable and insightful estimates of the nature and effects of innovative activity. The model clarifies how current levels of technology interact with current innovation opportunities to determine profits.

The most compelling insight is that conventional wisdom about how opportunities for innovation evolve may not apply to modern high-tech industries. The results show that the automobile industry is the only one that evolves as described by Utterback and Abernathy (1975) and Klepper (1996): the estimated rate of quality improvement is highest early on when firm numbers are rising and the estimated rate of cost improvement is highest later on. The other industries exhibit a variety of patterns, but in every case the estimated rate of quality improvement does not decline as the industries evolve.

Future research should develop data and models that explore some more subtle changes that occur over the life cycle, like changes in the timing of innovation and diffusion. Richer environments with heterogeneous choices, network effects, and brand effects also deserve further study. For example, an extension to environments in which some firms specialize in imitation (Nelson (1988), Eeckhout and Jovanovic (1998)) would be a useful next step.

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Appendix A: Formal Results

The following result is used below. When low-tech firms are in the market, firms' value functions differ only by current profits, and V_t^0 can be expressed as

$$\begin{aligned}V_t^0 = \quad & \max_{x_q,x_c}[\pi_t^0 - x_q - x_c + \delta(\lambda_q(x_q)\lambda_c(x_c)\pi_{t+1}^{qc} \\ & +\lambda_q(x_q)(1-\lambda_c(x_c))\pi_{t+1}^{q} + (1-\lambda_q(x_q))\lambda_c(x_c)\pi_{t+1}^{c} \\ & +(1-\lambda_q(x_q))(1-\lambda_c(x_c))\pi_{t+1}^{0}) - \delta\pi_{t+1}^0].\end{aligned} \tag{4.1}$$

This implies that investments depend only on profits in the following period. Because $p_t^q = \frac{\gamma_t^q}{\gamma_t^0}p_t^0$ and quality and cost parameters are exogenous, profits for each type of firm are a function of p_t^0. Therefore, if p_{t+1}^0 is known, optimal investments in period t can be computed. Given the investments, the only remaining unknown in (4.1) is p_t^0. The condition $V_t^0 = 0$ can be used to solve for p_t^0. Therefore, given p_{t+1}^0, p_t^0 can be obtained.

4.1.1. Quality Innovations

Consider an industry with only quality innovations in which $\gamma_{t+1}^0 = \eta\gamma_t^0$ for all t, where $\eta > 1$. This implies that $p_t^q = \eta p_t^0$. The condition $V_t^0 = 0$ can be written as follows:

$$\max_{x_q}[\pi_t^0(p_t^0) - x_q + \delta\lambda_q(x_q)(\pi_{t+1}^q(\eta p_{t+1}^0) - \pi_{t+1}^0(p_{t+1}^0))] = 0. \tag{4.2}$$

Price is constant over time. To see this, let $p_t^0 = p_{t+1}^0 = p^0$. The envelope theorem implies that the left-hand side of equation (4.2) is increasing in p^0 (the expression is increasing in $(\pi_{t+1}^q(\eta p^0) - \pi_{t+1}^0(p^0))$, and $\pi_{t+1}^q(\eta p^0) - \pi_{t+1}^0(p^0)$ and $\pi_t^0(p^0)$ are increasing in p^0). If $p^0 = 0$, the expression equals $-f^0$, and as $p^0 \to \infty$ the expression must be positive. Continuity of the profit functions implies that a unique p^0 satisfies equation (4.2).

Since the prices and costs are constant, q_t^q and q_t^0 are constant. Further analysis requires further assumptions. If high-tech firms are a small fraction of the total, average price and quantity are approximately p^0 and q^0. Increasing quality may either shift market demand out or in and result in either an increase or a decrease in market quantity.[9] If high-tech firms are a small fraction of the total, firm numbers follow the pattern in market quantity.

4.1.2. Variable-Cost Innovations

Consider an industry with only variable-cost innovations. Assume that $c(a,q) = c(aq)$ and that $a^0_{t+1} = \zeta a^0_t$ for all t, where $0 < \zeta < 1$. All firms face the same price, p. Each firm's optimal quantity can be expressed as $q = \frac{1}{a}c'^{-1}\left(\frac{p}{a}\right)$. Low-tech and high-tech profits can be expressed as functions of $\frac{p_t}{a^0_t}$. The equilibrium price path is $p_{t+1} = \zeta p_t$ for all t (use the method in the previous subsection). Given this, $\frac{p_t}{a^0_t}$ is constant, π^c_t and π^0_t are constant, investment is constant, and $q_{t+1} = \frac{1}{\zeta}q_t$. Thus, price falls and quantity per firm rises.

Market quantity rises as price falls. Under the assumption that n^c_t is a small fraction of the total, using the market clearing condition, $\frac{n_{t+1}}{n_t} \simeq \frac{Q_{t+1}q^0_t}{q^0_{t+1}Q_t} = \frac{Q_{t+1}\zeta}{Q_t}$, where n_t represents total firm numbers in period t. Firm numbers increase if $\frac{Q_{t+1}}{Q_t} > \frac{1}{\zeta}$, and decrease otherwise. If the price elasticity of demand is less than $-\frac{1}{\zeta}$ when prices are high and exceeds $-\frac{1}{\zeta}$ when prices are low (as is the case with a linear demand curve), then as a^0_t falls firm numbers rise and then fall. Hopenhayn (1994) obtains a similar result.

4.1.3. Fixed-Cost Innovations

Consider an industry with only fixed-cost innovations, and assume that $f^0_t - \vartheta = f^0_{t+1}$, where $\vartheta > 0$. The condition $V^0_t = 0$ can be written as follows:

$$\max_{x_c}[\pi^0_t - x_c + \delta\lambda_c(x_c)\vartheta] = 0. \tag{4.3}$$

Clearly x_c is constant. Therefore, as f^0_t falls p^0_t must fall to keep π^0_t constant. Firm entry causes p^0_t to fall. As p^0_t falls, q^c_t and q^0_t fall because variable costs remain unchanged while firms face a lower price. Further, as p^0_t falls market quantity rises.

[9] Quality improvements can reduce demand for units even when demand for services rises. For example, improving the life of a light bulb may decrease the number of lightbulbs sold per period because fewer bulbs need to be replaced.

Appendix B: The Estimation Method

Assume that low-tech firms are in the market in every period. Given an initial set of values for d_0, d_1, d_2, d_3, w_1, w_2, w_3, w_4, w_5, w_6, α_q, α_c, b_0, b_1, b_2, b_3, and δ, simulate the model: Start at the last period, T, and set p_T^0 (the estimation method estimates p_T^0). Calculate investments and p_{T-1}^0 as described in Appendix A. Repeat the procedure to obtain prices and investments for every period. Given prices compute the quantities produced by each type of firm.

Next, compute firm numbers. At $t = 1$, all firms are low-tech firms, and n_1^0 can be obtained using the market-clearing condition. With the investments and n_1^0 numbers of the various types of high-tech firms in period 2 can be obtained. For example, $n_2^{qc} = \lambda_q(x_q)\lambda_c(x_c)n_1^0$. With n_2^{qc}, n_2^q, n_2^c, the quantities, and the prices, obtain n_2^0 using the market-clearing condition. Repeat this procedure to obtain firm numbers for each type of firm in every period.

Then compute summary measures. For example, the number of firms in period t is given by $n_t^{qc}+n_t^q+n_t^c+n_t^0$. Average price, market quantity, and average quality can all be calculated. Then compute the distance between the firm numbers series the model generates and the firm numbers data, the distance between the price series the model generates and the price data, etc. Choose parameters of the model to minimize a weighted distance function.

Formally, assuming that the logged data are generated by the logs of the model's industry observables plus normally-distributed random-error terms,

$$\ln n_t^* = \ln n_t + \epsilon_{nt} \tag{4.4}$$

$$\ln Q_t^* = \ln Q_t + \epsilon_{Qt} \tag{4.5}$$

$$\ln p_t^* = \ln p_t + \epsilon_{pt} \tag{4.6}$$

$$\ln \gamma_t^* = \ln \gamma_t + \epsilon_{\gamma t} \tag{4.7}$$

$$\ln n_t^{qc*} = \ln n_t^{qc} + \epsilon_{n^{qc}t}, \tag{4.8}$$

$$\ln n_t^{q*} = \ln n_t^q + \epsilon_{n^q t}$$

$$\ln n_t^{c*} = \ln n_t^c + \epsilon_{n^c t} \tag{4.9}$$

where the data are distinguished by asterisks. The error terms are independent of each other and over time, with variances given by σ_n^2, σ_Q^2, σ_p^2, σ_γ^2, $\sigma_{n^{qc}}^2$, $\sigma_{n^q}^2$, and $\sigma_{n^c}^2$, with the exception of the error terms on firm numbers and quantity.[10] The model allows for some observations to be missing. For example, suppose that n, Q, p, and γ are observed every period, n^{qc} and n^q are observed in some periods, and n^c is never observed. Define Σ as follows:

$$\Sigma = \begin{bmatrix} \sigma_n^2 & \sigma_{Qn} & 0 & 0 \\ \sigma_{Qn} & \sigma_Q^2 & 0 & 0 \\ 0 & 0 & \sigma_p^2 & 0 \\ 0 & 0 & 0 & \sigma_\gamma^2 \end{bmatrix},$$

where σ_{Qn} represents the covariance between ϵ_{nt} and ϵ_{Qt}. Define Σ^{n^q} as follows:

$$\Sigma^{n^q} = \begin{bmatrix} \sigma_{n^q}^2 & 0 \\ 0 & \sigma_{n^{qc}}^2 \end{bmatrix}.$$

Let $I_t^{n^q}$ be an indicator function that takes on the value 1 when n_t^q is observed and 0 otherwise. The value of the likelihood function at date t is given by

$$L_t = \frac{1}{(2\pi)^2}|\Sigma|^{-.5}\exp^{\{-\frac{1}{2}\epsilon_t\Sigma^{-1}\epsilon_t'\}}\,\frac{1}{(2\pi)^{I_t^{n^q}}}|\Sigma^{n^q}|^{-.5I_t^{n^q}}\exp^{\{-\frac{1}{2}\epsilon_t^{n^q}(\Sigma^{n^q})^{-1}(\epsilon_t^{n^q})'\}},$$

where $\epsilon_t = [\epsilon_{nt}\ \epsilon_{Qt}\ \epsilon_{pt}\ \epsilon_{\gamma t}]$ and $\epsilon_t^{n^q} = I_t^{n^q}[\epsilon_{n^q t}\ \epsilon_{n^{qc} t}]$ (the last three terms in L_t reduce to the value 1 when n_t^q is not observed.) The likelihood is the product of the L_t terms:

$$L = \Pi_{t=1}^T L_t, \tag{4.10}$$

where T represents the number of observations. Parameters d_0, d_1, d_2, d_3, w_1, w_2, w_3, w_4, w_5, w_6, α_q, α_c, b_0, b_1, b_2, b_3, p_T^0, σ_n^2, $\sigma_{n^q}^2$, $\sigma_{n^{qc}}^2$, σ_p^2, σ_Q^2, σ_γ^2, and σ_{nQ} are estimated for each industry by maximum likelihood, and δ is set at .96. Preliminary likelihood ratio tests led to dropping some parameters in some cases.

[10]The errors on firm numbers and market quantity are assumed to be correlated in order to improve the match between the quantity-per-firm series that the model generates and the quantity-per-firm series in the data.

The Industries

Fig. 1. Automobiles: Firm Numbers, Price, Market Quantity, and Quality

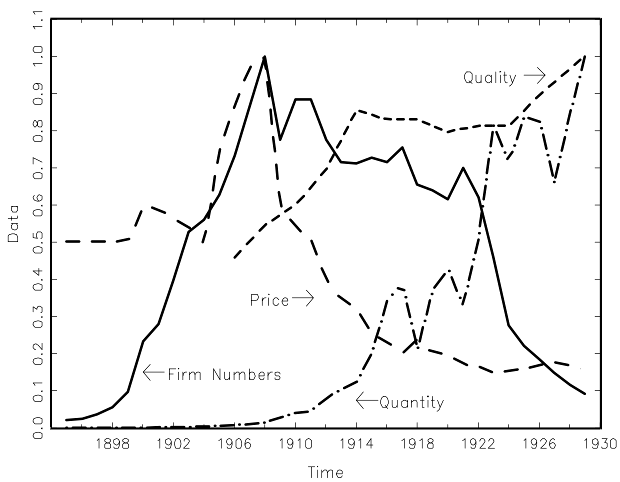


Fig. 2. Computers: Firm Numbers, Price, Market Quantity, and Quality

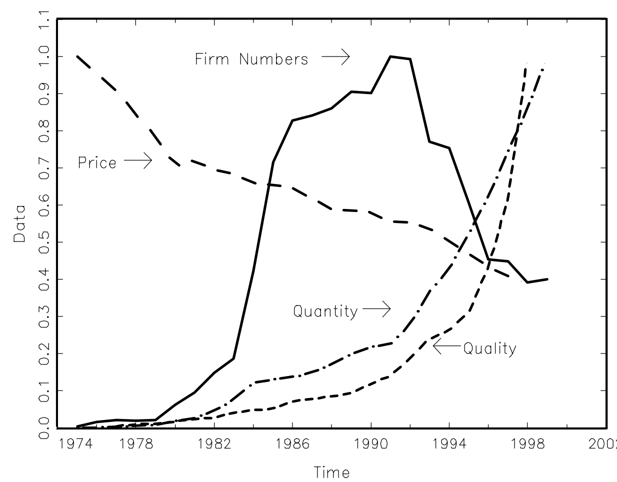


Fig. 3. Disk Drives: Firm Numbers, Price, Market Quantity, and Quality

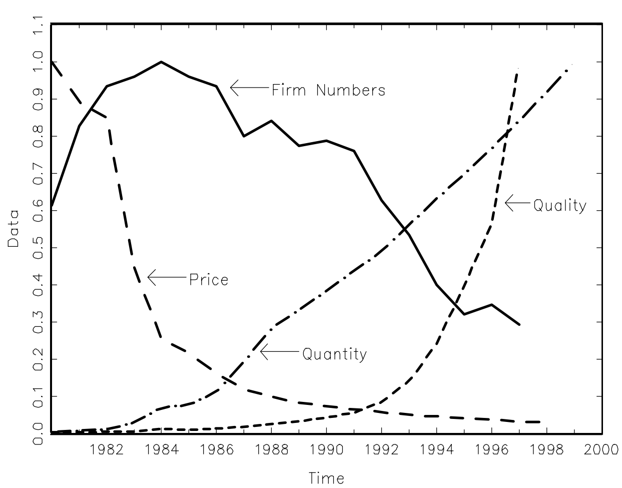


Fig. 4. Monitors: Firm Numbers, Price, Market Quantity, and Quality

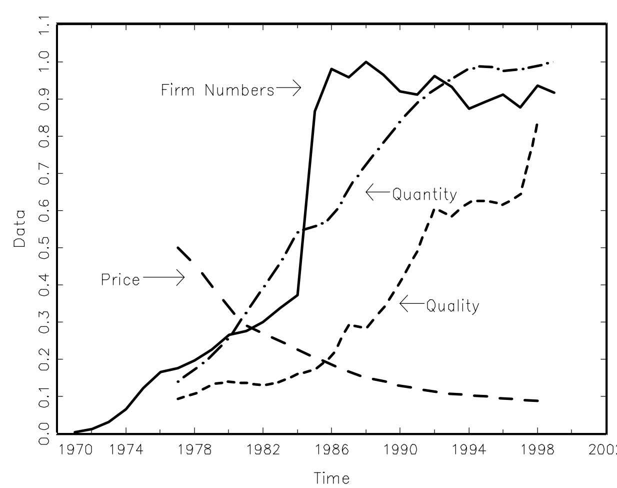
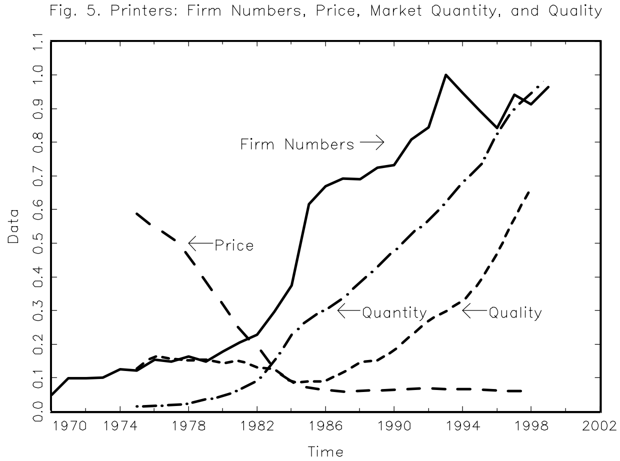


Fig. 5. Printers: Firm Numbers, Price, Market Quantity, and Quality



The Automobile Industry (1895-1929)

Fig. 6. Firm Numbers, Price, and Market Quantity
(Solid lines: data Dashed lines: simulation results)

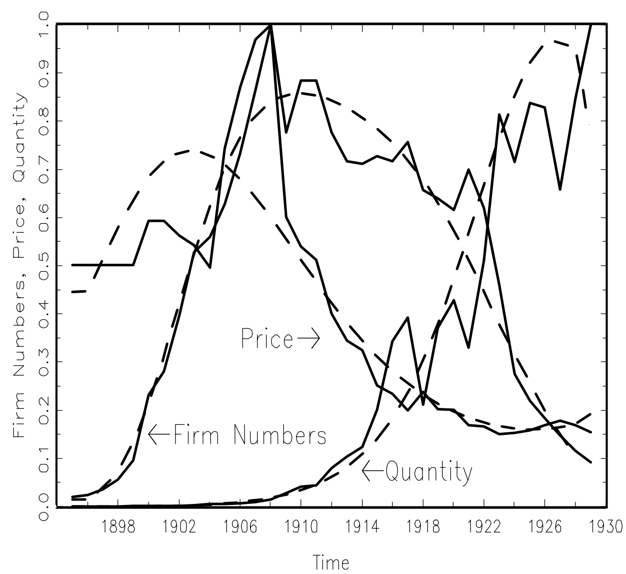


Fig. 7. Estimated Avg. Quality, Variable Cost Parameter, and Fixed Cost

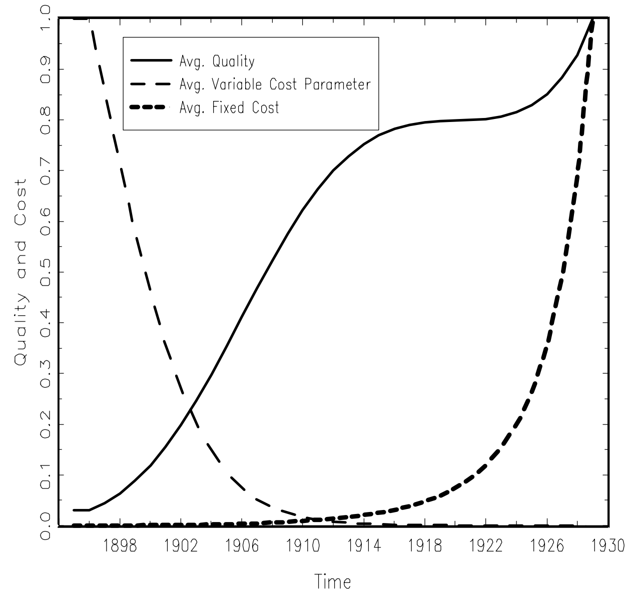


Fig. 8. Profits of the Various Types of Firms

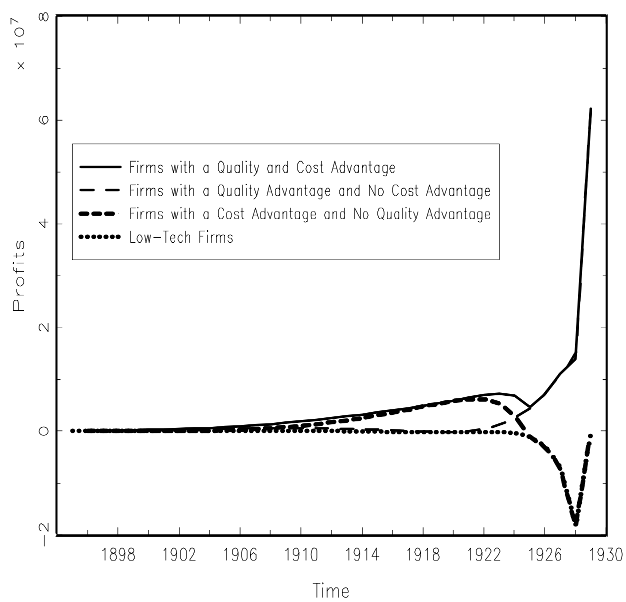
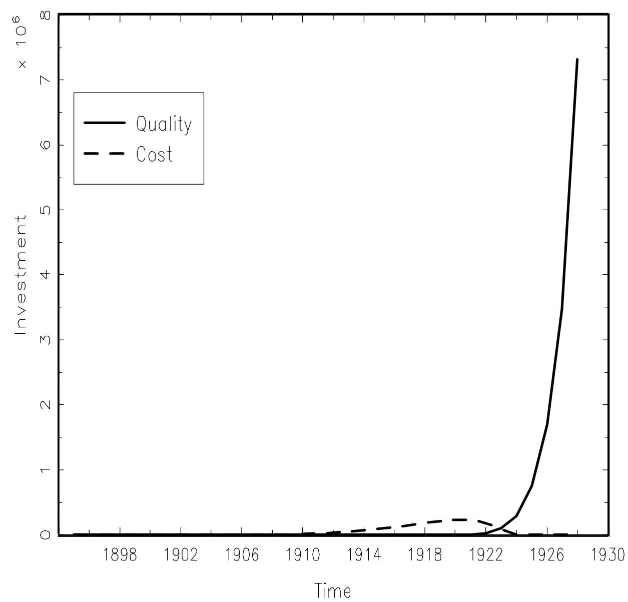


Fig. 9. Investment in Quality and Cost Improvements



The Personal Computer Industry (1975-1999)

Fig. 10. Firm Numbers, Price, and Market Quantity
(Solid lines: data Dashed lines: simulation results)

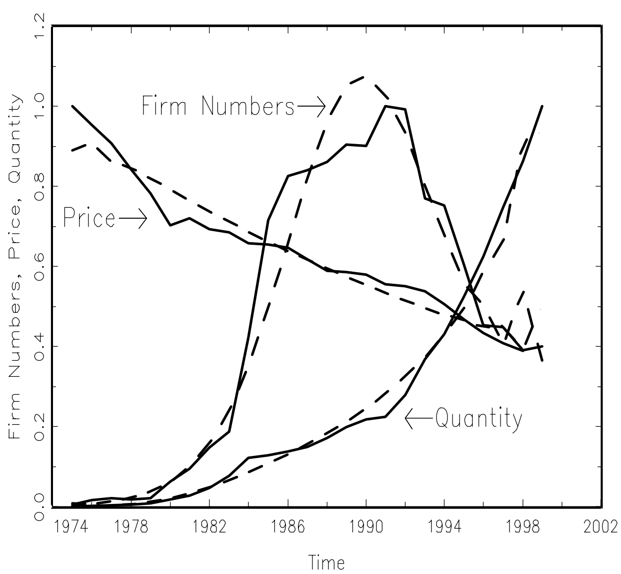


Fig. 11. Estimated Avg. Quality, Variable Cost Parameter, and Fixed Cost

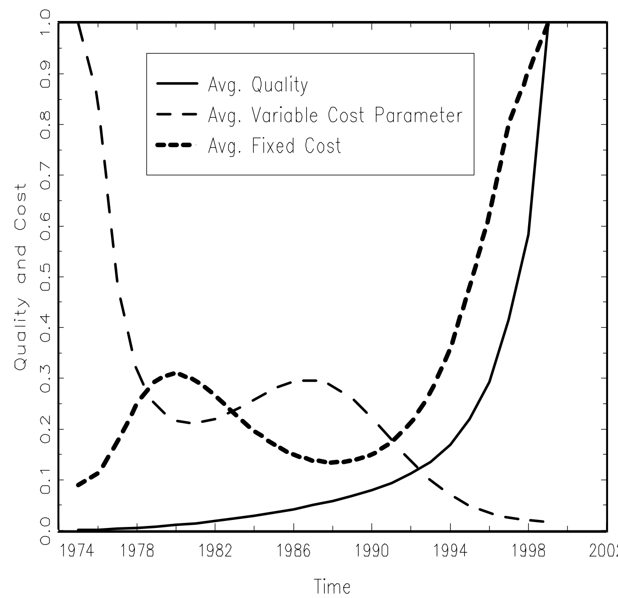


Fig. 12. Profits of the Various Types of Firms

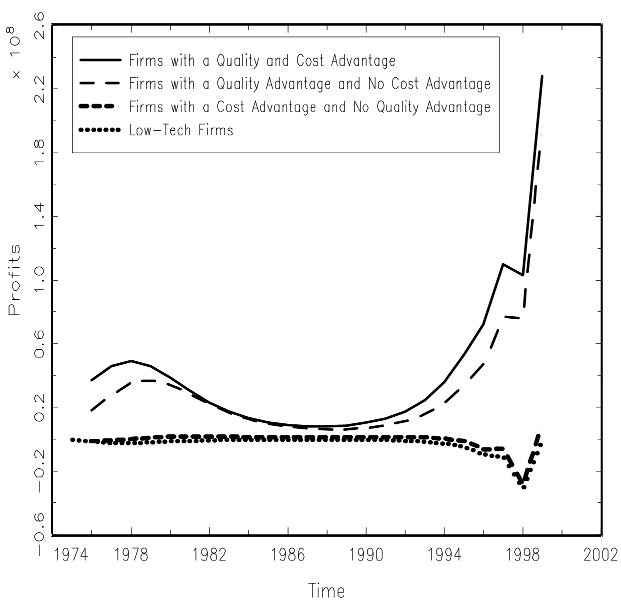
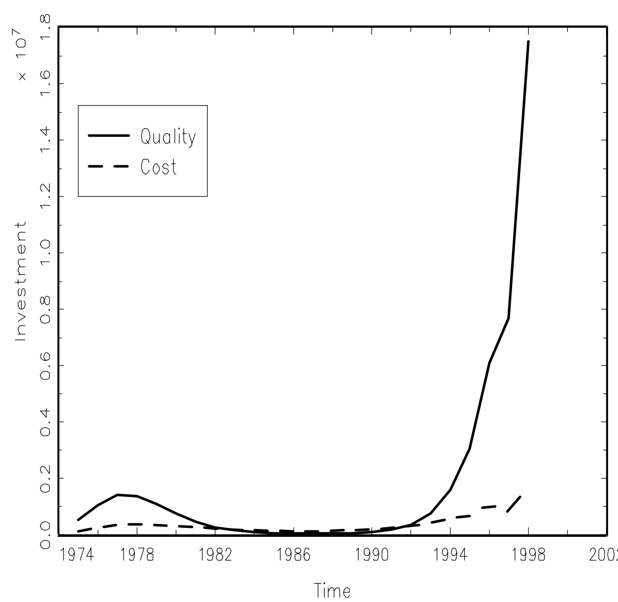


Fig. 13. Investment in Quality and Cost Improvements



The Rigid Disk Drive Industry (1980-1999)

Fig. 14. Firm Numbers, Price, and Market Quantity
(Solid lines: data Dashed lines: simulation results)

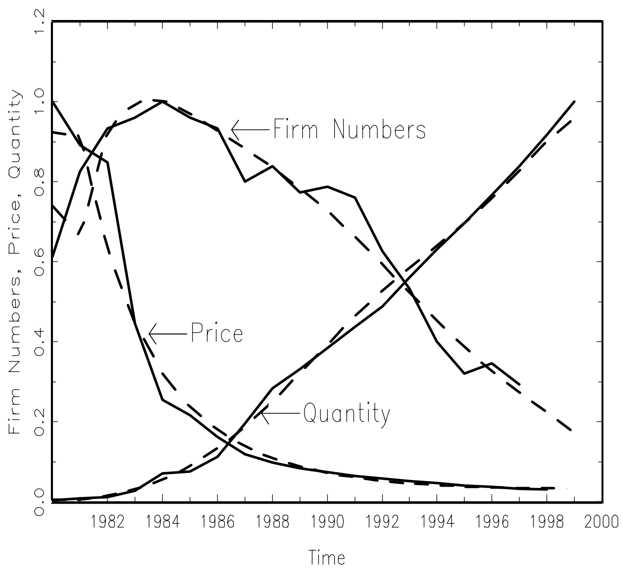


Fig. 15. Estimated Avg. Quality, Variable Cost Parameter, and Fixed Cost

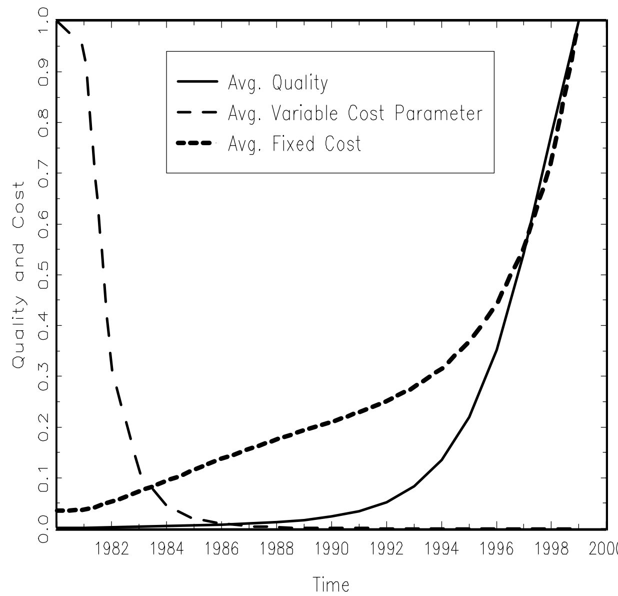


Fig. 16. Profits of the Various Types of Firms

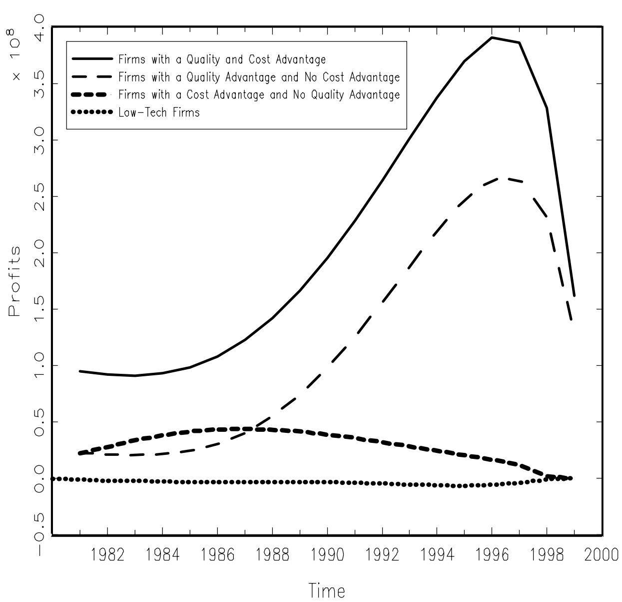
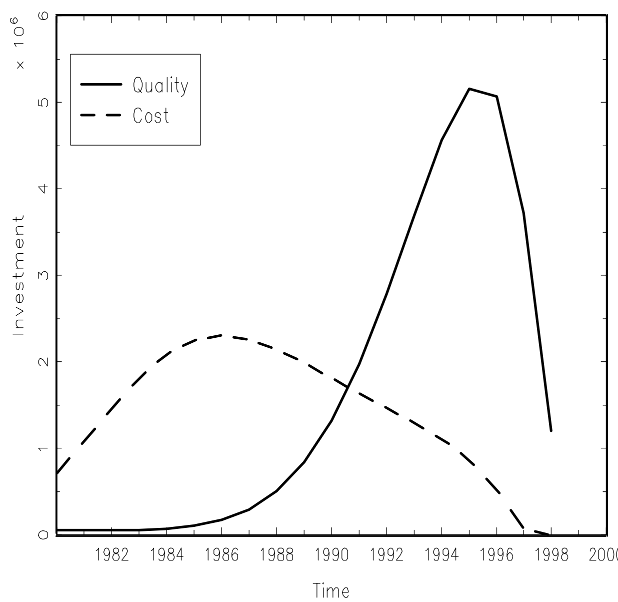


Fig. 17. Investment in Quality and Cost Improvements



The Computer Monitor Industry (1971-1999)

Fig. 18. Firm Numbers, Price, and Market Quantity
(Solid lines: data Dashed lines: simulation results)

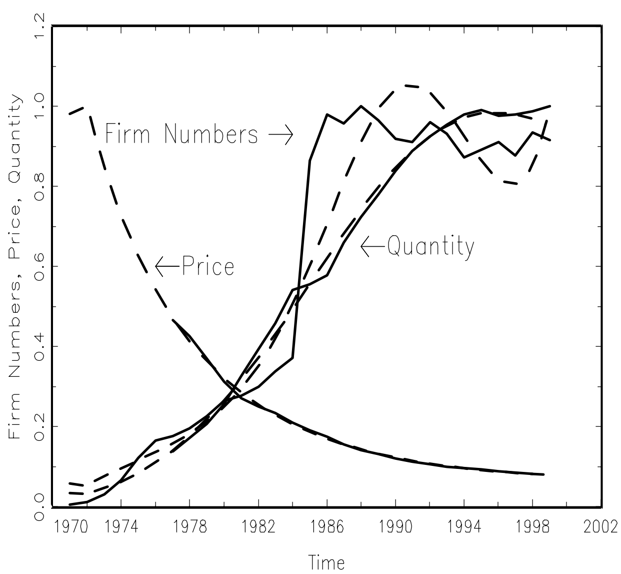


Fig. 19. Estimated Avg. Quality, Variable Cost Parameter, and Fixed Cost

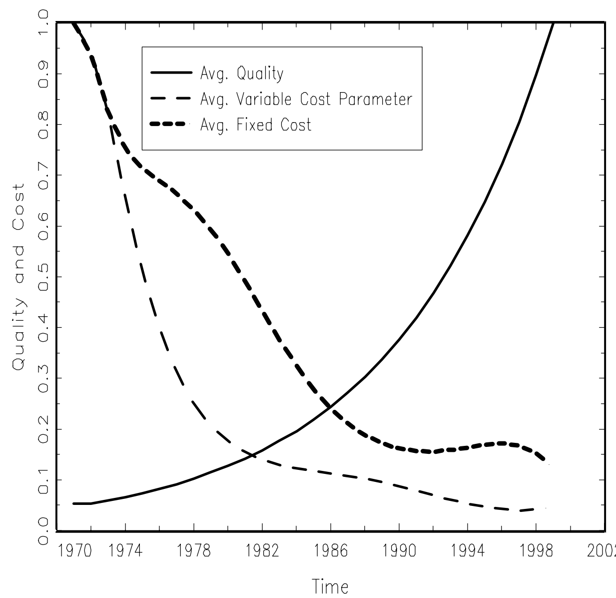


Fig. 20. Profits of the Various Types of Firms

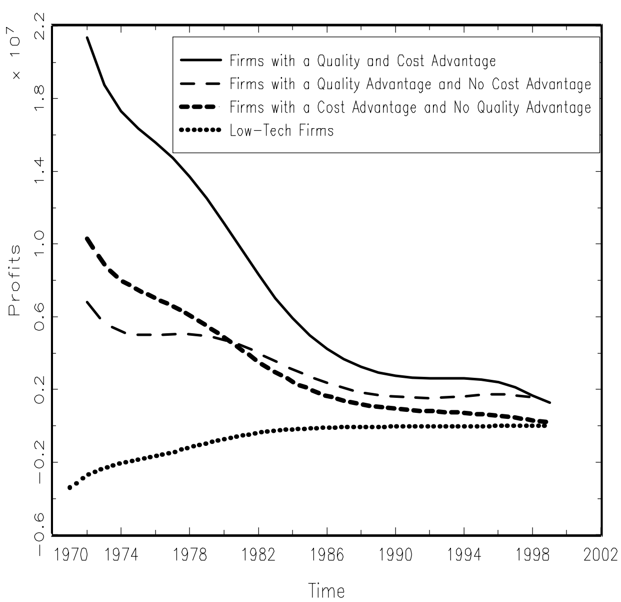
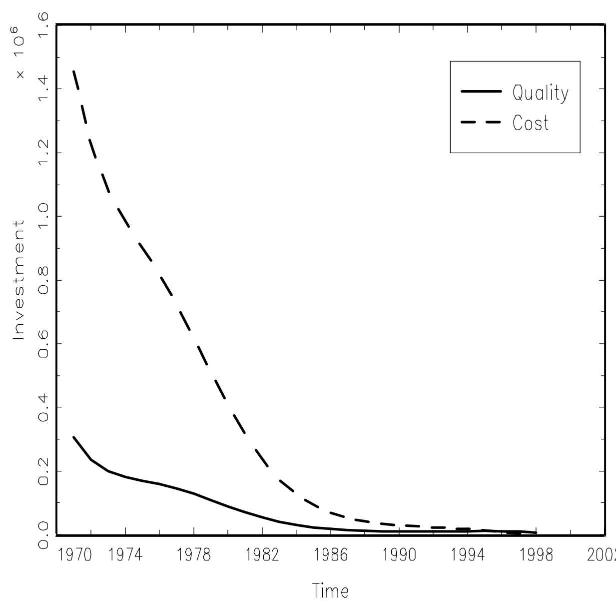


Fig. 21. Investment in Quality and Cost Improvements



The Computer Printer Industry (1970-1999)

Fig. 22. Firm Numbers, Price, and Market Quantity
(Solid lines: data Dashed lines: simulation results)

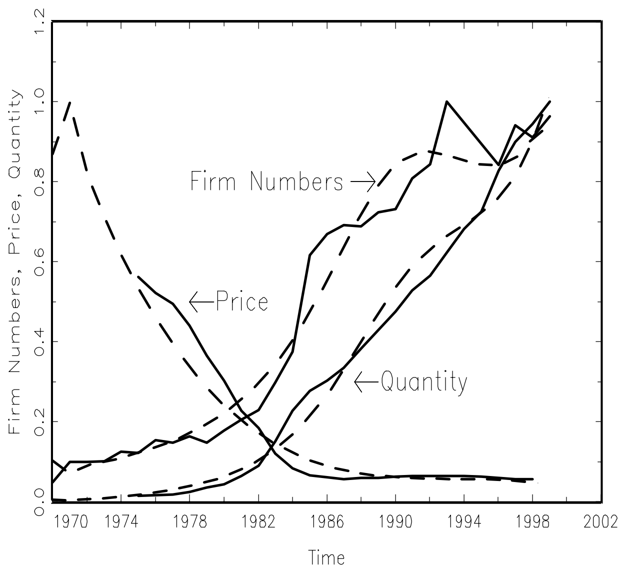


Fig. 23. Estimated Avg. Quality, Variable Cost Parameter, and Fixed Cost

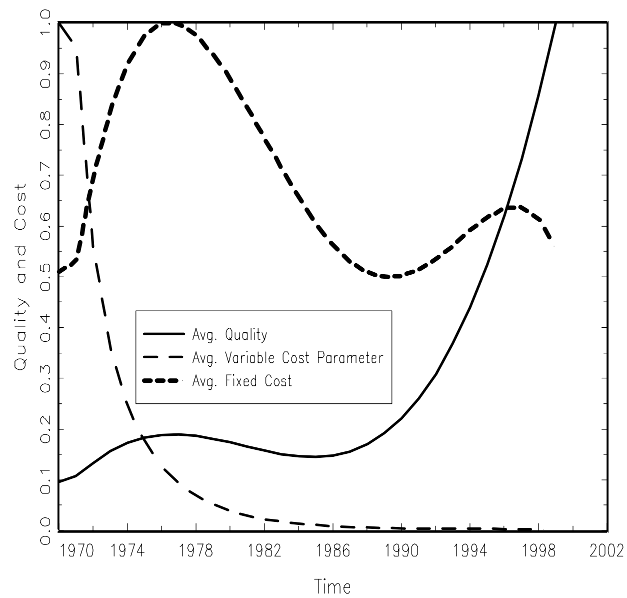


Fig. 24. Profits of the Various Types of Firms

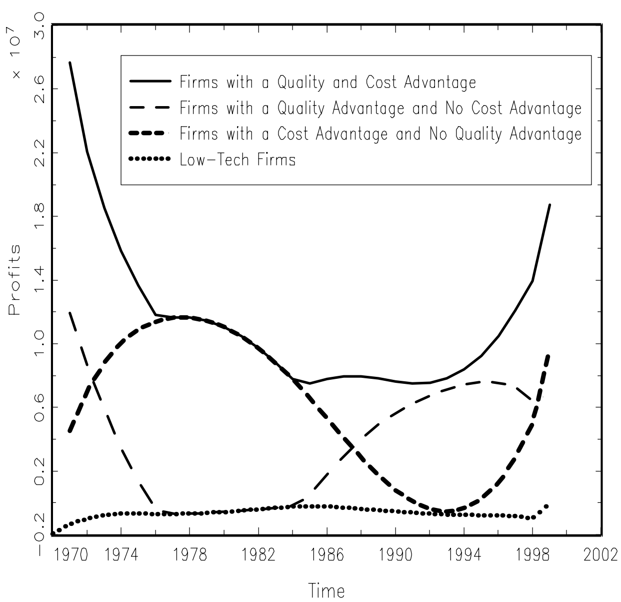


Fig. 25. Investment in Quality and Cost Improvements

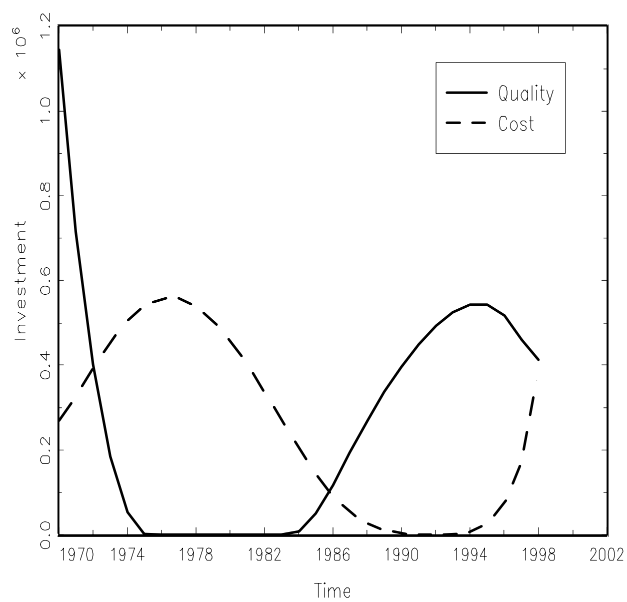


Table 1. Effects of Improvements on Observables

	Observable			
Improvement	**Price**	**Mkt. Quantity**	**Firm Numbers**	**Quantity/Firm**
Quality	None	Varies	Varies	None
Variable-Cost	Down	Up	Varies	Up
Fixed-Cost	Down	Up	Up	Down

Table 2. Estimated Average Annual Rate of Change in Average Quality by Stage

	Stage		
Industry	**Stage 1**	**Stage 2**	**Stage 3**
Automobile	0.25	0.031	0.032
Computer	0.34	0.17	0.38
Disk Drive	0.0046	0.36	0.53
Monitor	0.11	0.11	-
Printer	0.035	0.14	-
Average	0.15	0.16	0.31

Automobile Stage 1: 1895-1908; Stage 2: 1909-1922; Stage 3: 1923-1929.
Computer Stage 1: 1975-1986; Stage 2: 1987-1992; Stage 3: 1993-1999.
Disk Drive Stage 1: 1980-1981; Stage 2: 1982-1991; Stage 3: 1992-1999.
Monitor Stage 1: 1971-1985; Stage 2: 1986-1999.
Printer Stage 1: 1970-1984; Stage 2: 1985-1999.

Table 3. Estimated Average Annual Rate of Change in the Average Variable-Cost Parameter by Stage

	Stage		
Industry	**Stage 1**	**Stage 2**	**Stage 3**
Automobile	-0.22	-0.32	-0.25
Computer	-0.086	-0.11	-0.26
Disk Drive	-0.05	-0.51	-0.29
Monitor	-0.14	-0.059	-
Printer	-0.26	-0.12	-
Average	-0.15	-0.22	-0.26

Table 4. Estimated Average Annual Rate of Change in Average Fixed Cost by Stage

	Stage		
Industry	**Stage 1**	**Stage 2**	**Stage 3**
Automobile	0.36	0.24	0.36
Computer	0.072	0.064	0.25
Disk Drive	0.034	0.21	0.21
Monitor	-0.086	-0.054	-
Printer	0.024	-0.0098	-
Average	0.081	0.09	0.27

Table 5. Estimated Average Annual Profits from Quality and Cost Advantages by Stage (1983 dollars)

	Stage		
Industry/Type of Advantage	**Stage 1**	**Stage 2**	**Stage 3**
Automobile/Quality	298,627	239,701	14,560,351
Automobile/Cost	107,235	3,423,699	-3,008,900
Computer/Quality	22,744,028	7,642,974	67,235,081
Computer/Cost	851,163	1,102,150	-4,355,656
Disk Drive/Quality	22,401,596	50,984,007	212,677,740
Disk Drive/Cost	22,188,914	38,761,736	17,011,323
Monitor/Quality	4,658,169	1,697,398	-
Monitor/Cost	5,696,622	809,227	-
Printer/Quality	1,919,094	5,527,746	-
Printer/Cost	9,671,847	2,621,487	-